ENGINEERING CASE LIBRARY

ECL 152

PICKLE PASTEURIZER SHAFT FAILURE

Lady's Choice Foods in Hayward, California asked for outside help when the drive shaft failed on a major piece of their equipment, a pickle pasteurizer. The case analyzes the failure of the drive shaft and describes what was done to solve the problem.

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PICKLE PASTEURIZER SHAFT FAILURE

A drive shaft failure problem at Lady's Choice Foods was brought to our attention by Don Sampsel of Glass Containers Corporation in Fullerton, California. Mr. Sampsel indicated that Lady's Choice was looking for some outside help for the shaft problem on their seven month old pasteurizer. We visited Lady's Choice to learn first hand about the problem. While discussing the problem with Jake Tagorda, the plant superintendent, we mentioned the possibility of this problem being used in the classroom, but at that time there were no appropriate courses. Consequently, we didn't deal with the problem directly, but we did compile the following information because the failure presented an interesting machine design problem.

The sole product line marketed from the Haar Pickle Division of Lady's Choice in Hayward, California is 6000 tons of pickles per year.

The total employment in this plant at peak season is 125 hourly personnel and 5 salaried personnel. All engineering and equipment maintenance is overseen by Jess Robero.

The plant has no engineering design facilities. Non-standard items of equipment are designed and built through contracts with outside organizations.

Equipment Description

A major piece of their equipment, a new pasteurizer, cooler, and dryer unit, shown in Figure 1, was installed in the spring of 1968. This $92,000 unit consists of a 90 foot long chain belt conveyer 12 feet wide which conveys glass jars of pickles through a chamber which pasteurizes, cools and drys them. The chain belt slides on a stationary support bed. The drive system for this conveyer is schematically shown in Figures 2 and 3. The pasteurizing chamber shown in Figure 1 encloses essentially the full length of the conveyer. Physical details of the unit are included in the Appendix. The unit is designed to be

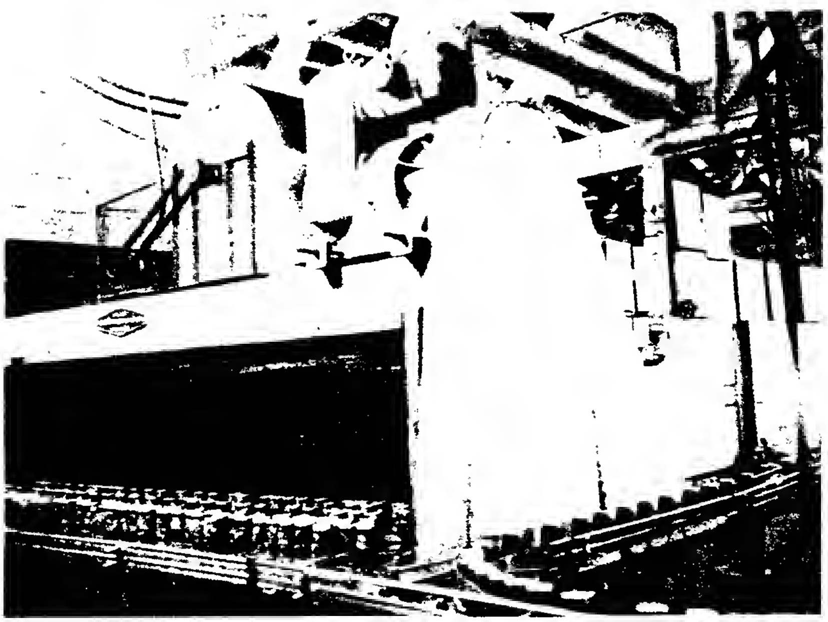


Figure 1

Photos of exit end of pasteurizer showing drive system (roller chain covered), woven chain belt (top photo) and jars exiting (bottom photo)

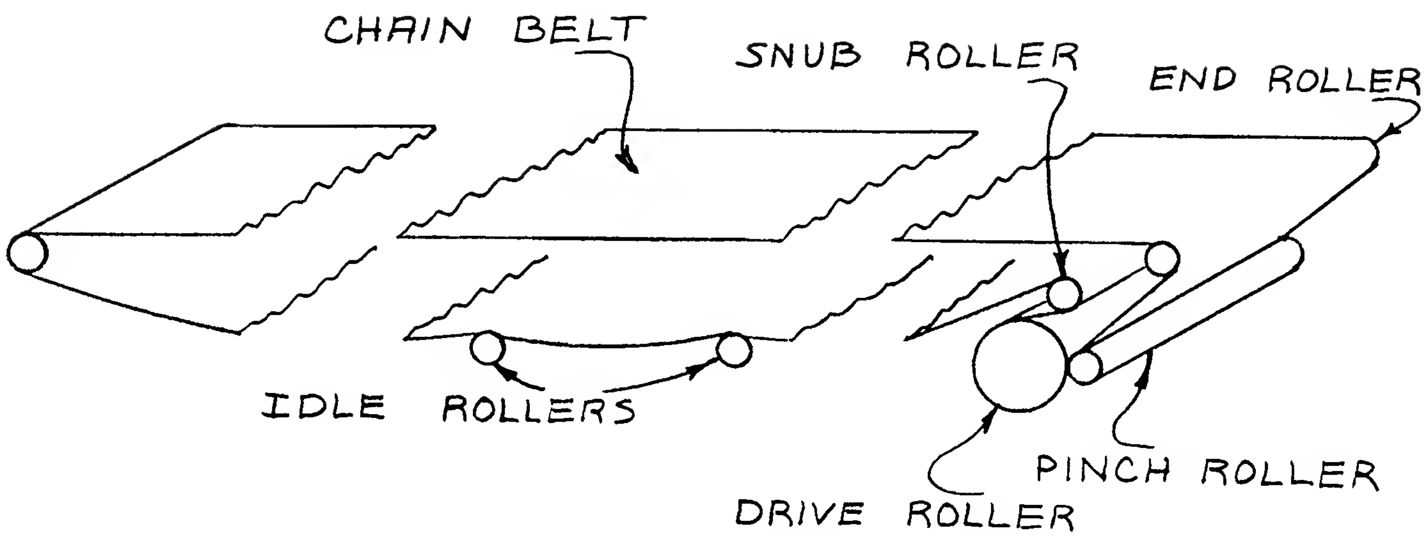


Figure 2

Conveyor Chain

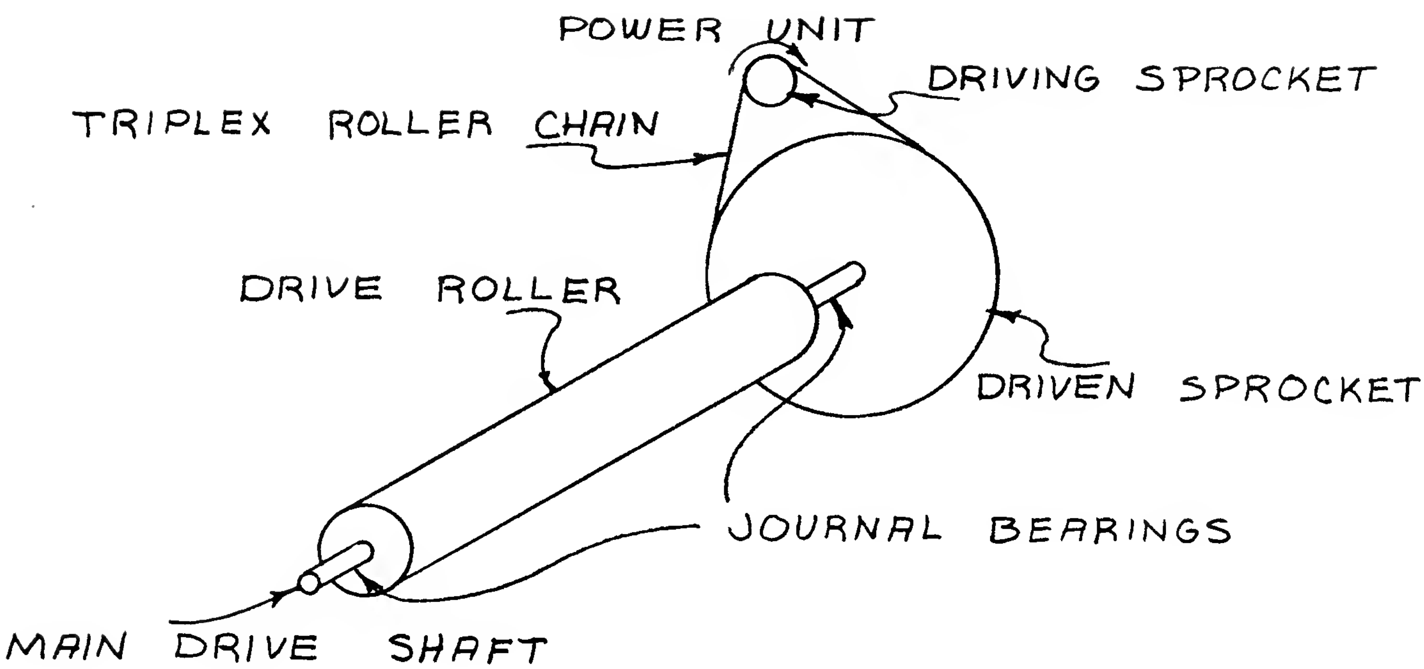


Figure 3

Drive System

loaded with as much as 11 tons of jars at one time and has been used with as much as 8 tons. The operating speed of the chain can be varied from 1.2 feet per minute to 1.7 feet per minute, depending on the size of the jars being processed.

The drive system, schematically shown in Figure 3, is powered by a 5 horse power electric motor with an integral, variable speed drive. The driving sprocket, which is mounted on the output shaft of the power unit, engages a triplex roller chain which transmits the power to a six foot diameter driven sprocket. The driven sprocket is keyed to a shaft which is held in two journal bearings and passes through and is welded to the drive roller. The drive roller is a rubber covered steel cylinder with an overall diameter of 21-1/2 inches. There are several circular half-inch reinforce plates in the cylinder. The pasteurizer unit was modeled after an existing smaller unit, and the drive roller shafts of both units were the same diameter.

The Failure

After approximately 1800 hours of operation during a six to seven month period, the 3-7/16" diameter drive roller shaft failed where indicated in Figure 4. At the time of failure, the pasteurizer unit was in continuous operation and loaded with only 1800 pounds of jars.

The surface of the failed cross-section was reported to have been rusted across approximately one-half of the diameter. It was also observed that the failure section passed through the keyway which transmits torque from the driven sprocket to the drive roller shaft.

We discussed possible sources of trouble. Was the main drive shaft large enough? Did the keyway cause a significant stress concentration? Did the engagements of the sprocket teeth with the roller chain cause a perturbation in the stress level in the drive shaft? Did transverse vibrations of the drive chain cause perturbations in the stress level in the main drive shaft? Did the elasticity of the system and

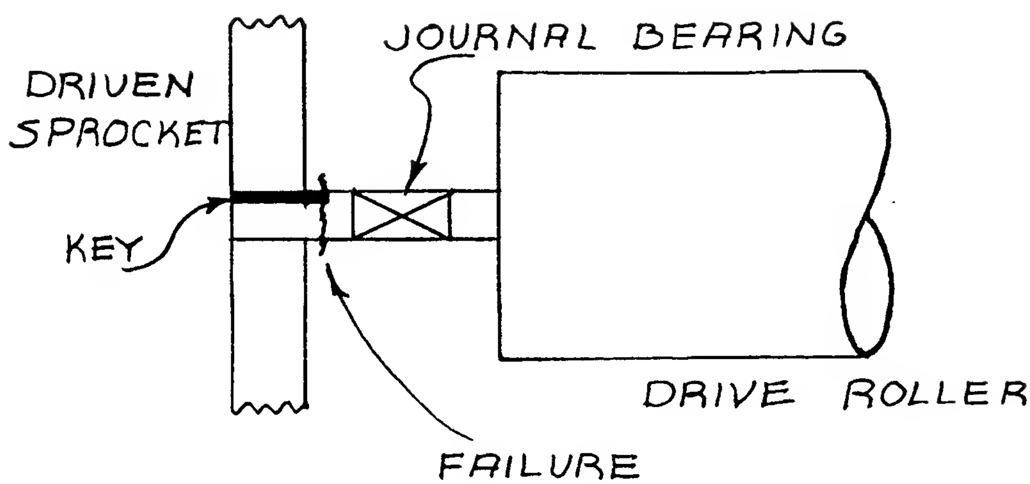


Figure 4

Location of Failure

especially the chain belt allow stick slip to occur between the chain belt and its supporting bed? Could the shaft have had a manufacturing defect? Did the dynamic load imposed on the shaft during start-up cause stresses in the shaft significantly higher than stresses obtained during continuous operation? Was drag due to improper chain belt tracking, causing excess power requirements? Jess Robero indicated that they had always experienced some trouble with the tracking of the chain belt.

What Was Done

The failure was reported to the manufacturer of the unit. They proceeded to repair the roller assembly by welding a new similarly sized shaft to the roller. Mr. Robero did not accept the repaired roller because he felt the shaft was undersized. At this time he obtained outside professional engineering help to support his opinion and as a result, the new roller assembly having a 6" diameter shaft was manufactured and installed. This new roller assembly has been used for several months without difficulty.

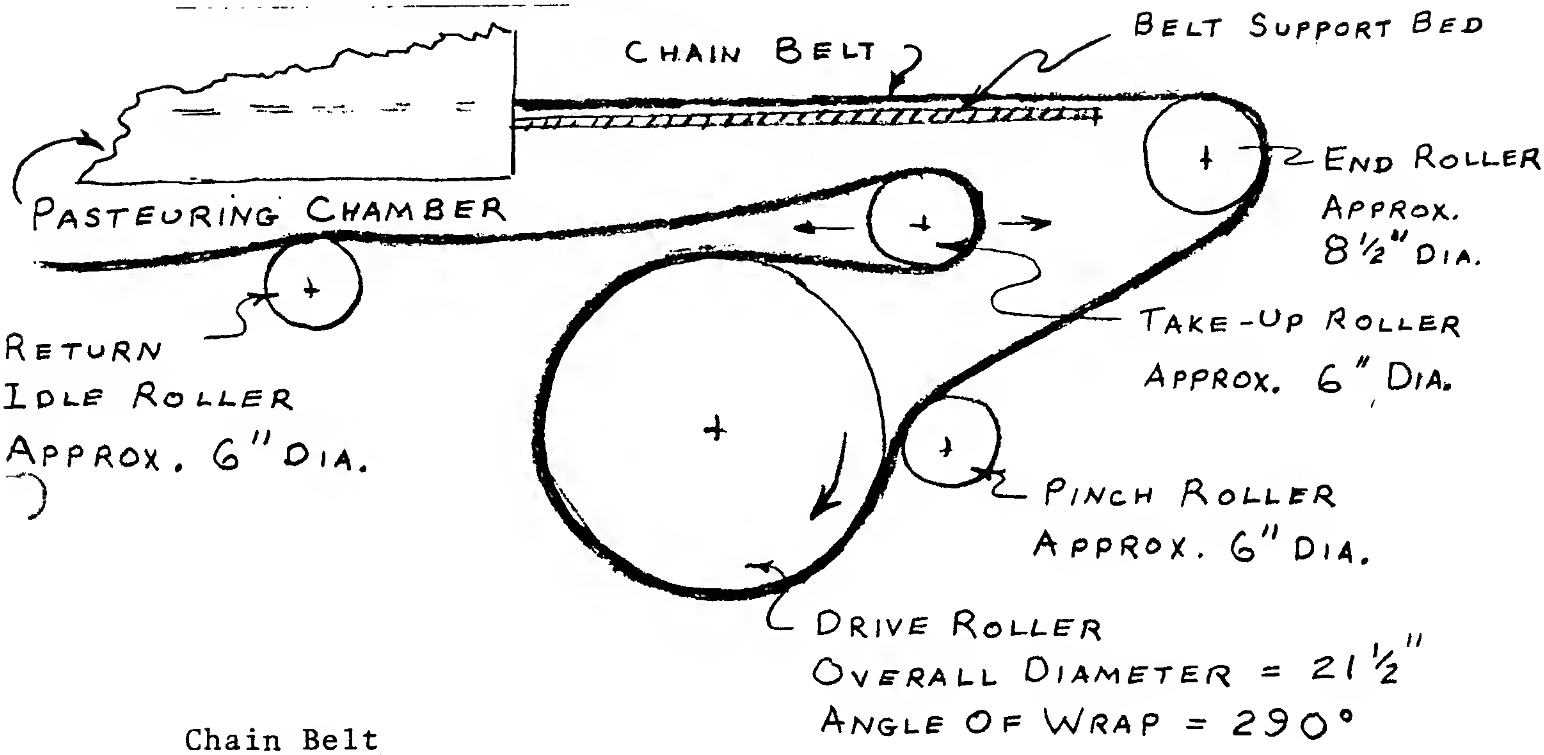
APPENDIX

Equipment Details

Pasteurizer, Drier, and Cooler Unit

Physical Details from
Blueprints and Measurements

Chain Belt Conveyor System



Chain Belt

Belt is 12' wide x about 177' total length of which about 86' is in the box.

Belt weight 4-1/2 lb/ft^2

Ultimate strength 44,040 lbs/ft of width at room temperature

Belt is woven from galvanized steel wire of 60,000 psi tensile strength

Belt rides on a 12' wide herringbone bed that is coated with ethelene propaline

Rollers

All rollers fabricated from tubing

Rollers (continued)

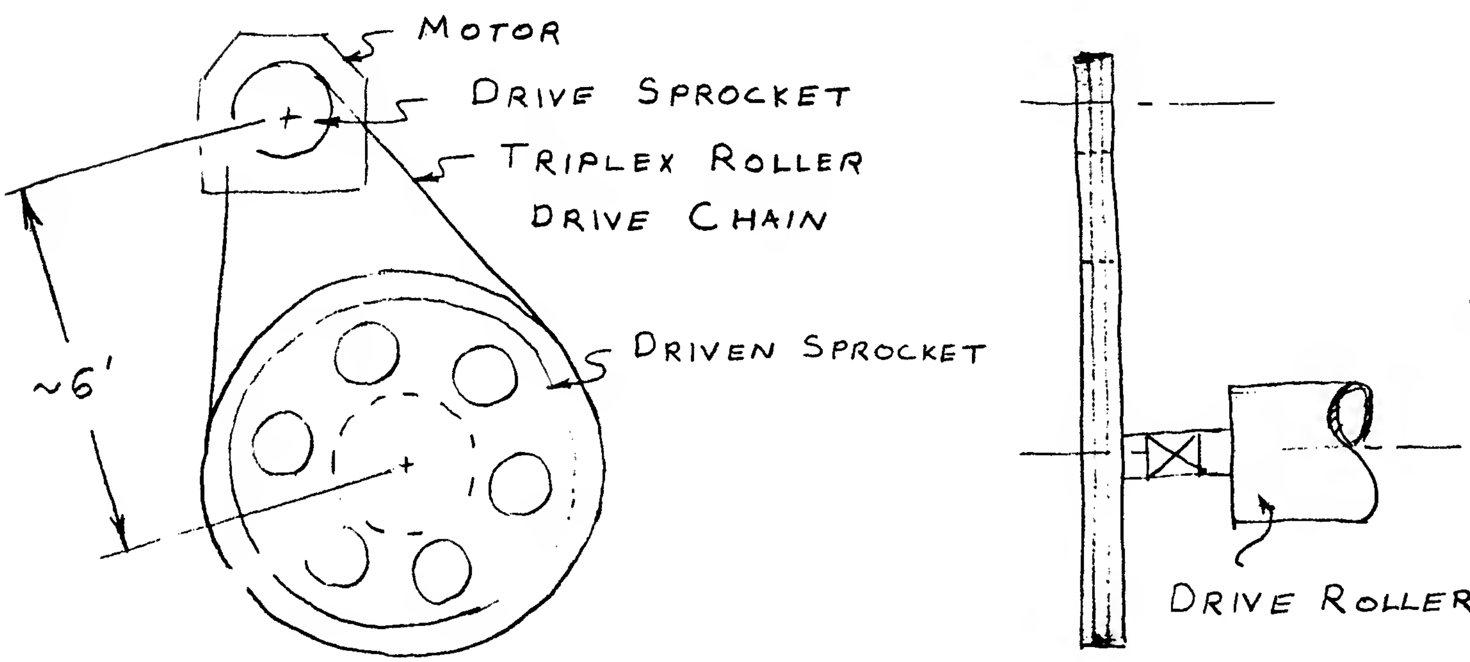
Return idle rollers fabricated from 12' lengths of 6" pipe @ 19#/ft

14 return rollers weight = (14 rollers)(12 ft/roller)(19#/ft) =3200#

Two 1-1/2" diameter x 18" long (6#/ft) end shafts per roller contribute a weight of (28 shafts)(1-1/2 ft/shaft)(6 #/ft) = 252#

Total weight of return pulleys and shafts = 3452#

Power Transmission



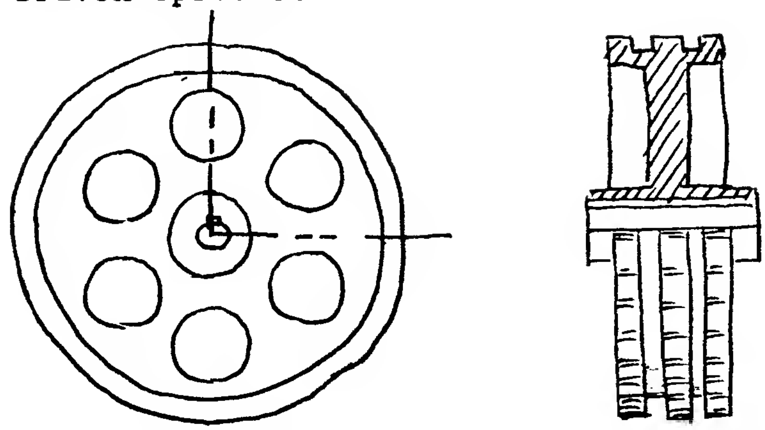
Motor: 5 hp vari drive, U. S. electric motor with variable output from 1.4 to 12.4 rpm

Drive Sprocket: 20 tooth triplex sprocket ∿ 15" dia

Chain: #160 triplex roller chain 2" (single) pitch with 1-1/8" dia rollers; wt = 19.6 lbs/ft

Driven Srpocket: 112 tooth triplex sprocket ∿ 72" dia

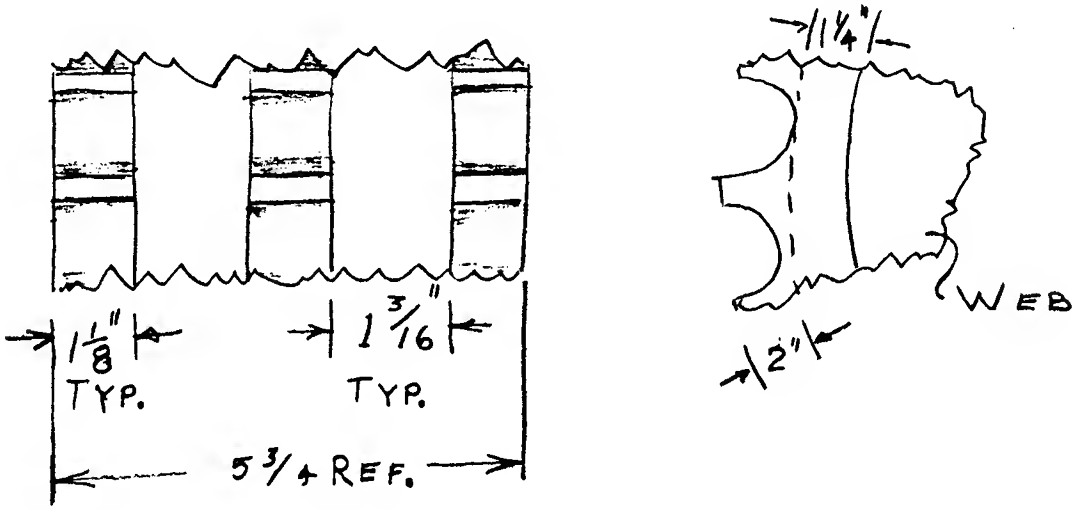
Driven Sprocket:



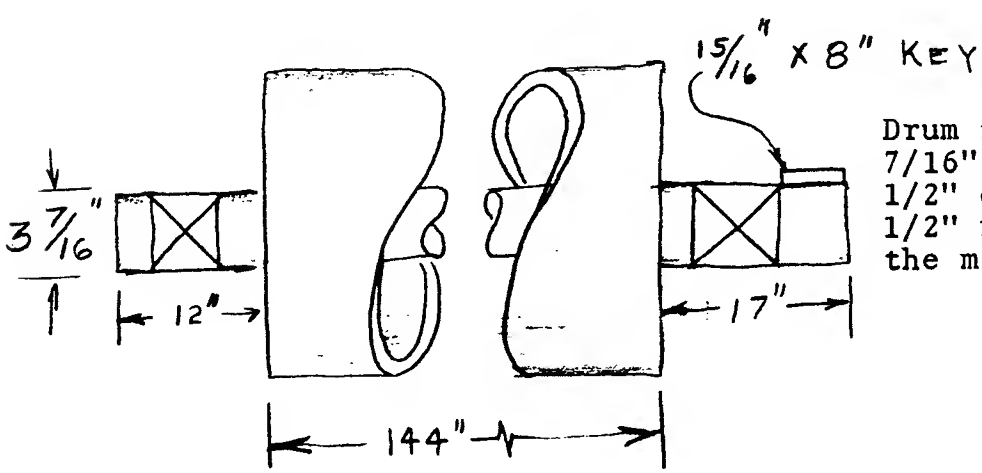
Hub: 8" dia x 7-1/2" long with 15/16" keyway

Web: Fabricated from 1-1/4" plate with 6 14" dia holes on 38" dia "bolt" circle

Rim:



Drive Roller:



Drum fabricated from 7/16" rolled plate with 1/2" end plates and several 1/2" reinforcing plates in the middle

APPENDIX

Drive Roller (continued): Overall diam 21-1/2"
Roller is covered with 1/2" rubber to provide friction surface

Speed: a) chain belt speed ∿ 1.2 ft/min for 32 oz. jars → 130 jars/min for 4" dia jars

b) varied up to 1.7 ft/min for other size jars

Load: Max load of jars could be as high as 34,200 lbs.

APPENDIX

Instructor's Note

Some Stress Calculations and Questions

Assuming that the system is started with a load of 16,000 lbs of jars which is the maximum amount put through the unit before the failure, the pull F on the belt is estimated to be μN where $\mu = .3$ (from Mark's handbook for laminated plastic on steel) and N is the normal force. Therefore,

$$N = 16{,}000 + \text{weight of the belt}$$

$$N = 16{,}000 + (4\ 1/2\ \text{lb/ft}^2)\ (12'\ \text{wide})\ (86'\ \text{long}) = 20{,}640$$

$$F = \mu N = .3(20{,}640) = 6{,}200\ \text{lbs}$$

The belt tension F acts at a moment arm of about 11" about the center of the drive shaft.

So

$$\text{Torque} = T = 6{,}200\ (11) = 68{,}200\ \text{in-lb}$$

To carry this torque with the 3 7/16" shaft the maximum shear stress τ is

$$\tau = \frac{Tc}{J} = \frac{68{,}200(1.72)(32)}{\pi(3.437)^4}$$

$$\tau = 8{,}600\ \text{psi}$$

How is the shear stress influenced by the keyway and associated stress concentrations?

The force tending to bend the shaft at the point of failure is the tension in the chain which is

$$\text{tension} = t = \frac{T}{r} = \frac{68{,}200\ \text{in-lb}}{36\ \text{in}} = 1{,}890\ \text{lb}$$

The moment at the point of failure is estimated to be

$$M = 4''(1{,}890\ \text{lb}) = 7{,}550\ \text{in-lb}$$

which results in a maximum stress σ due to bending of

$$\sigma = \frac{Mc}{I} = \frac{7,550(1.72)(4)}{\pi(1.72)^4} = 1,890 \text{ psi}$$

Can the maximum stress due to bending which completely reverses every revolution be neglected?*

The amount of torque available will have a direct influence on the dynamic loading during startup. With a belt speed of 1.2 ft/min and drum radius of 11 in. the drum rotates at 1.3 rad/min or about 0.2 rpm. The torque T available in the drum shaft (with a transmission efficiency of 0.8) becomes

$$T = 5 \text{ hp}(0.8)(33,000 \frac{\text{ft-lb}}{\text{min-hp}})(\frac{12 \text{ in}}{\text{ft}})(\frac{\text{min}}{0.2(2\pi)\text{rad}})$$

$$T = 1,260,000 \text{ in-lb}$$

Was the steady-state load assumption used in the shear and bending stress calculations valid?

Is there a better configuration for the drive system? Would the use of an intermediate shaft as shown in Figure N1 help? Is there any advantage in replacing the roller chain drive system with an appropriate gear drive system?

Is it feasible technically and economically to carry the jars on a series of shorter chain belts as schematically shown in Figure N2? Are there any problems related to the transfer of the jars from one belt to the next?

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* for further consideration see Shigley, "Mechanical Engineering Design," McGraw-Hill, 1963, pp 183-189, or similar mechanical design text.

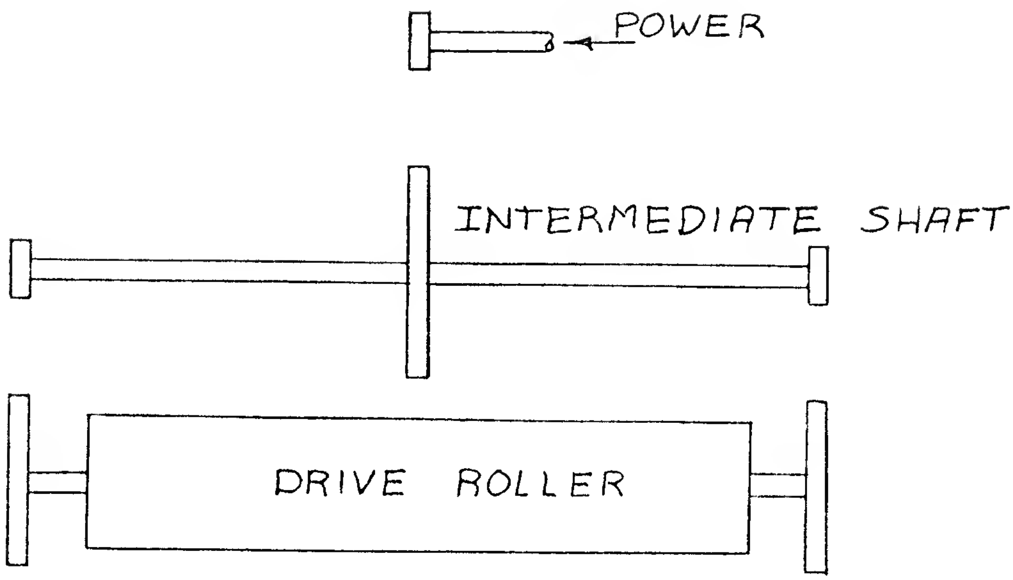

Figure N1

A Drive System

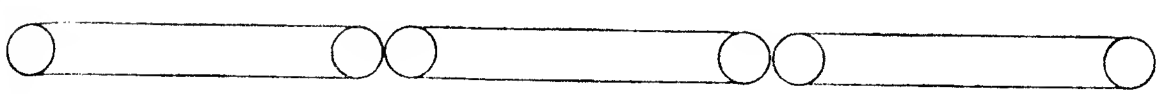

Figure N2

Schematic of Chain Belts